(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 694 209 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
**12.07.2000 Bulletin 2000/28**

(21) Application number: **94914072.7**

(22) Date of filing: **07.04.1994**

(51) Int. Cl.[7]: **H01L 21/302**, H01L 21/463, H01L 31/032

(86) International application number:
**PCT/US94/03827**

(87) International publication number:
**WO 94/24696 (27.10.1994 Gazette 1994/24)**

(54) **ENHANCED QUALITY THIN FILM Cu(In,Ga)Se 2 FOR SEMICONDUCTOR DEVICE APPLICATIONS BY VAPOR-PHASE RECRYSTALLIZATION**

DÜNNE SCHICHT VON Cu (In,Ga)Se 2 MIT VERBESSERTER QUALITÄT DURCH DAMPFPHASENREKRISTALLISATION FÜR HALBLEITERVORRICHTUNGEN

COUCHE MINCE DE Cu(In,Ga)Se 2 DE QUALITE AMELIOREE DESTINEE A DES APPLICATIONS RELATIVES A DES DISPOSITIFS A SEMICONDUCTEURS ET PRODUITE PAR RECRISTALLISATION EN PHASE VAPEUR

(84) Designated Contracting States:
**BE DE FR GB NL**

(30) Priority: **12.04.1993 US 45860**

(43) Date of publication of application:
**31.01.1996 Bulletin 1996/05**

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## Description

**[0001]** The United States Government has rights in this invention under Contract No. DE-AC02-83CH10093 between the U.S. Department of Energy and the National Renewable Energy Laboratory, a Division of Midwest Research Institute.

## Technical Field

**[0002]** The present invention is related generally to preparation of thin film compounds and more particularly to preparing thin film compounds of $Cu(In,Ga)Se_2$ in semiconductor devices.

## Background Art

**[0003]** Thin films of copper-indium-diselenide ($CuInSe_2$), copper-gallium-diselenide ($CuGaSe_2$), and copper-indium-gallium-diselenide ($CuIn_{1-x}Ga_xSe_2$), all of which are sometimes generically referred to as $Cu(In,Ga)Se_2$, have become the subject of considerable interest and study for semiconductor devices in recent years. They are of particular interest for photovoltaic device or solar cell absorber applications because of solar energy to electrical energy conversion efficiencies that have been shown to exceed fifteen percent (15%) in active areas and to approach fourteen percent (14%) in total areas, which is quite high for current state-of-the-art solar cell technologies. It is generally believed by persons skilled in this art that the best electronic device properties, thus the best conversion efficiencies, are obtained when the mole percent of copper is about equal to the mole percent of the indium, the gallium, or the combination of the indium and gallium in the $Cu(In,Ga)Se_2$ compound or alloy. The selenium content will not generally be important to the electronic properties of the semiconductor if the growth conditions supply sufficient selenium so that it comprises about fifty atomic percent (50 at. %) of the $Cu(In,Ga)Se_2$ compound to form the desired crystal lattice structures. Sulfur can also be, and sometimes is, substituted for the selenium, so the compound is sometimes referred to even more generically as $Cu(In,Ga)(S,Se)_2$ to comprise all of those possible combinations.

**[0004]** While growth of single crystal $CuInSe_2$ has been studied, such as in the U.S. patent No. 4,652,332, issued to *T. Ciczek*, the use of polycrystalline thin films is really more practical. Sputter depositing a ternary single phase $CuInSe_2$ layer, including the ability to determine the properties of the thin film, such as multilayer structures, by varying the sputter process parameters, is described by the U.S. patent No. 4,818,357, issued to *Case et al.* However, the two fabrication methods of choice are: (1) Physical vapor deposition of the constituent elements, exemplified by the process disclosed in the U.S. patent no. 5,141,564, issued to *Chen et al.*, is generally used as a research tool; and (2) The selenization of Cu/In metal precursors by either $H_2Se$ gas or Se vapor. The selenization technology generally exemplified by the processes described in the U.S. patent no. 4,798,660, issued to *Ermer et al.*, the U.S. patent no. 4,915,745, issued to *Pollock et al.*, and the U.S. patent no. 5,045,409, issued to *Eberspacher et al.*, is currently favored for manufacturing processes. However, thin films produced by the selenization processes usually suffer from macroscopic spacial nonuniformities that degrade performance and yield, and reproducible consistent quality from run to run is difficult to obtain and unpredictable.

**[0005]** An article by J. R. Tuttle et al., AIP Conference Proceedings 268, Photovoltaic Advanced Research & Development Project, Denver, CO, 1992, Pages 186-193 relates to a " novel processing and device structure in thin-film $CuInSe_2$-based solar cells". This article reports the resulting film morphology and XRD spectra of representative $Cu_2Se$-$CuInSe_2$ mixtures in this composition range, deposited at about 500°C are shown in Figs. 1 and 2, respectively, for 7059 glass and Mo/SLS substrates.

**[0006]** In accordance with the present invention, a process for fabricating thin-film semiconductor devices as set forth in claim 1 is provided. Preferred embodiments of the invention are disclosed in the dependent claims.

## Disclosure of Invention

**[0007]** Accordingly, it is a general object of this invention to provide a process that produces a better quality $Cu(In,Ga)Se_2$ thin film more consistently and more predictably than previously known processes.

**[0008]** It is also an object of this invention to provide a method of producing high quality $Cu(In,Ga)Se_2$ homojunctions.

**[0009]** Another object of the present invention is to provide a process that is capable of fabricating films of $Cu(In,Ga)Se_2$ that are smooth and do not require additional processing for photovoltaic characteristics that have applications in solar and non-solar cell functions.

**[0010]** Still another object of this invention is to provide a process for producing high quality $Cu(In,Ga)Se_2$ thin films that does not require precise control of the ratio of Cu/(In,Ga), thus can be scaled up easily to production of large areas and to commercial quantities.

**[0011]** Additional object, advantages, and novel features of the present invention shall be set forth in part in the description that follows, and in part will become apparent to those skilled in the art upon examination of the following or may be learned by the practice of the invention or may be realized and attained by means of the instrumentalities and in combinations particularly pointed out in the appended claims.

**[0012]** To achieve the foregoing and other objects and in accordance with the purpose of the present invention, as embodied and broadly described herein,

the method of this invention may comprise the steps of forming a Cu-rich, phase-separated, compound mixture comprising $Cu(In,Ga)Se_2$:$Cu_xSe$ on a substrate, and converting $Cu_xSe$ in the mixture to $Cu_w(In,Ga)_ySe_z$ by exposing the $Cu_xSe$ to (In,Ga) and Se. This conversion should be done at elevated temperatures, preferably in the range of 300-600°C.

## Brief Description of Drawings

**[0013]** The accompanying drawings, which are incorporated in and form a part of the specifications, illustrate the preferred embodiments of the present invention, and together with the description serve to explain the principles of the invention.

Figure 1 is a cross-sectional view of a beginning stage of ternary two phase polycrystalline growth of $CuInSe_2$:$Cu_xSe$ on a conducting substrate in a first step of a preferred embodiment process according to the present invention;

Figure 2 is a cross-sectional illustration of an intermediate polycrystalline growth stage of the first step of the preferred embodiment process of this invention;

Figure 3 is a cross-sectional illustration of the final stage of the first step of the preferred embodiment process of this invention;

Figure 4 is a cross-sectional illustration of the beginning of the second step of the preferred embodiment process of this invention;

Figure 5 is a cross-sectional illustration of another optional resulting polycrystalline structure produced according to the present invention that is suitable for heterojunction applications;

Figure 6 is a cross-sectional illustration of one optional resulting polycrystalline structure produced according the present invention that is suitable for homojunction applications;

Figure 7 is a $Cu_2Se$-$In_2Se_3$ pseudobinary phase diagram that is useful in describing and understanding the processes of the present invention;

## Detailed Description of the Preferred Embodiments

**[0014]** The processes of the present invention comprise essentially two steps for fabricating high-quality thin film $Cu(In,Ga)Se_2$ - based semiconductor devices that have photovoltaic effects and are especially adaptable for solar cell applications. For purposes of simplicity, the description of the processes and claims of this invention will focus primarily on $CuInSe_2$ - based structures. However, it should be understood that Ga or various combinations of $In_{1-x}Ga_x$ may be substituted for the In component described in these processes and that such substitutions are considered to be equivalents for purposes of this invention. Also, as mentioned above, where several elements can be combined with or substituted for each other, such as In and Ga, in the component to which this invention is related, it is not uncommon in this art to include those combineable or interchangeable elements in a set of parentheses, such as (In,Ga). The descriptions in this specification sometimes utilizes this convenience. Finally, also for convenience, the elements are discussed with their commonly accepted chemical symbols, including copper (Cu), indium (In), germanium (Ga), selenium (Se), hydrogen (H), and molybdenum (Mo), and the like.

**[0015]** The first step of this invention is to deposit or grow a high conductivity, very Cu-rich, ternary, phase-separated mixture of monocrystalline or large-grain $[CuInSe_2]_\delta$:$[Cu_xSe]_{1-\delta}$ ($0 \le \delta \le 1$, $1 \le x \le 2$), followed by an annealing and recrystallization of the $Cu_xSe$ phase. The second step includes keeping the temperature high enough to maintain a liquid rich $Cu_xSe$ environment and depositing In-rich material, such as In and Se sequential or co-deposition or the binary $In_ySe$, in a Se gas overpressure environment to form the desired $CuIn_xSe_y$ compound, as will be described in more detail below.

**[0016]** Referring now to Figure 1, the first step of a preferred embodiment process according to this invention may start by beginning the deposition of the Cu-rich thin film of $CuInSe_2$:$Cu_xSe$ on a substrate 12. The substrate 12 may be, for example, soda-lime silica glass or amorphous 7059 glass. The deposition can be on the bare glass substrate 12, but it may be preferred to include a smooth metallic surface 14, such as a 2000Å layer of molybdenum (Mo).

**[0017]** As illustrated in the phase diagram of Figure 7, when the Cu, In, and Se components are in the Cu-rich range, i.e., where the mole % of In and Se is in the range between 0-50%, and at temperatures under about 790°C, the $CuInSe_2$ and $Cu_xSe$ phases are separated. Therefore, as Cu, In, and Se are deposited on the Mo-coated substrate 12 in Figure 1 in a very Cu-rich mixture, preferably comprising about 40-50 at. % Cu, at a substrate temperature greater than 500°C (preferably about 500-550°C), the $CuInSe_2$ crystalline structures 16 grow separate from the $Cu_xSe$ crystalline structures 18, i.e., they are phase-separated. Also, the melting point of the $Cu_xSe$ is slightly lower than the melting point of $CuInSe_2$. Therefore, it is preferable to maintain the substrate in the above-described temperature range, where the $CuInSe_2$ is a solid, and the $Cu_xSe$ is substantially in a liquid flux. Then, as the deposition process continues, as illustrated in Figure 2, the $CuInSe_2$ phase crystals 16 tend to grow together on the Mo layer 14, displacing the more liquid $Cu_xSe$ phase 18 outwardly. The end result of the deposition stage of the first step illustrated in Figure 3, is a large-grain $CuInSe_2$ phase 16 adhered to the

Mo coating 14 with an overlayer of the $Cu_xSe$ material 18 on its outer surface. If the $CuInSe_2$ and $Cu_xSe$ compounds are deposited sequentially or at lower temperatures, this structure is then preferably annealed in a Se atmosphere, such as Se or $H_2Se$ vapor, at a temperature of about 500-550°C. In this annealing stage, any solid $Cu_xSe$ 18 is convened to liquid $Cu_xSe$, and a growth/recrystallization is believed to occur in a liquid flux environment of the $Cu_xSe$ binary phase. This growth/recrystallization process encourages monocrystalline (112), large-grain growth (2-10 μm), which is a superior morphology for device quality electronic properties. The resulting structure of Figure 3 is referred to as the large-grain precursor 20, which forms the structural platform for a thin film electronic device fabricated according to the second step of this invention described below.

**[0018]** In the second step of a preferred embodiment of this invention, the excess $Cu_xSe$ 18 in the large-grain precursor structure 20 is convened to a $CuIn_ySe_z$ material by exposure to an activity of In and Se at elevated temperatures for a period of time, as illustrated in Figure 4. The In and Se exposure can be in the form of In vapor 22 and Se vapor 24, as illustrated in Figure 4, or it can be $In_ySe$ solid, such as the $In_2Se_3$ illustrated in Figure 7, with no Cu content. With the substrate 12 and large-grain precursor structure 20 maintained in the range of about 300-600°C, the $Cu_xSe$ overlayer 18 absorbs and combines with the In 22 to form the desired $CuIn_ySe_z$ material. Alternatively, this conversion of $Cu_xSe$ to a $CuIn_ySe_z$ material can be accomplished by sequential deposition of In and Se on the precursor structure 20. The characteristic of the $CuIn_ySe_z$ material can be controlled by the temperature maintained during this second step of the process, as described below.

**[0019]** A high temperature treatment option of the second step of the process, such as in the range of about 500-600°C, is illustrated in Figure 4, and the resulting nearly homogenous film structure 40 is shown in Figure 5. Essentially, at temperatures in the range of about 500-600°C, preferably at about 550°C, the $Cu_xSe$ overlayer 18 forms a liquid flux, while the $CuInSe_2$ underlayer 16 remains substantially solid. The In vapor 22 condenses to liquid phase 26 at the surface of the $Cu_xSe$ overlayer 18. The liquid In 26 and Se gas 24 contacts the overlayer 18, where it combines at the surface with the excess $Cu_xSe$ to form additional $CuInSe_2$, as shown at 28. This new $CuInSe_2$ remains in solution while it diffuses, as shown at 30, through the $Cu_xSe$ overlayer 18 to the liquid-solid interface 32, where it nucleates and "epitaxial" builds on the original $CuInSe_2$ crystalline structures 16, as shown at 34. The nucleation can be described as:

$$In(l)+Cu_xSe(l)+Se(g)\rightarrow CuInSe_2,$$

where (l) indicates liquid and (g) indicates gas. While it is not known for certain, it is believed that the lesser density of the $CuInSe_2$ in the $Cu_xSe$ assists in transferring the $CuInSe_2$ to the liquid-solid interface 38. In any event, this process results in a substantially continuous morphology homogenous film growth of the $CuInSe_2$ crystalline structures 16. When the liquid phase $Cu_xSe$ in the overlayer 18 is substantially consumed, the resulting film structure 40 may be near stoichiometric with planar surfaces, as shown in Figure 5. This recrystallization process is self-limiting in that, if the Se to In ratio is lowered, the process rejects In in the form of $In_ySe$ when the surface converts from Cu-rich to Cu-poor. It may be slightly Cu-rich or slightly Cu-poor, depending on the extend of $Cu_xSe$ recrystallization in this second step. However, the self-limiting nature of the reaction makes it unnecessary to regulate the In precisely, thus, the process is conducive to commercial processing. The nature of the surface 42 of structure 40 is known to be CU-poor with a composition equivalent to the $CuIn_3Se_5$ phase and is nearly planar and smooth. Proper engineering of this surface can lead to a layer of $CuIn_3Se_5$ of sufficient thickness to produce a shallow homojunction, which in turn may not require the thin CdS buffer layer to make an operational solar cell. This film structure 40, which is essentially p-type $CuInSe_2$, can be used on one side of a heterojunction device, as will be obvious to persons having ordinary skill in this art, by overlaying it with a different material, such as a CdS and ZnO window layer (not shown).

**[0020]** A lower temperature treatment option in the second step of the process of this invention, such as in the range of about 300-400°C, can produce a homojunction thin-film device 50, as shown in Figure 6, that does not require a different material overlay, such as a CdS and ZnO window layer, to have photovoltaic characteristics. In this optional lower temperature range treatment, the conversion of excess $Cu_xSe$ to a form of $CuIn_ySe_z$ is inhibited from approaching the stoichiometric ratio by the limited mobility of Cu at the lower temperatures, thus resulting in an overlayer 52 of very Cu-poor morphology, such as $Cu_2In_4Se_7$ in the ϒ' range or $CuIn_3Se_5$ in the ϒ" range of the phase diagram in Figure 7. Such Cu-poor structures in the overlayer 52 are n-type materials, in contrast to the p-type Cu-rich $CuInSe_2$ crystalline structures 16 underlaying the n-type layer 52. Therefore, the interface between the underlayer 16 and overlayer 52 forms a homojunction, and the film structure 50 can function as a photovoltaic device.

**[0021]** There are numerous practical options and variations for fabricating thin film devices according to this invention. Substitution of Ga or a combination of In and Ga for the In described above, as well as the option of using Se vapor, $H_2Se$ vapor, or $In_ySe_z$ solids have already been mentioned. In addition, there are many options for deposition. For example, the deposition can be accomplished by sputtering of the two compounds $CuInSe_2$ and $Cu_xSe$ in the first step either concurrently or sequentially, followed by or concurrently with Se treatment, or by co-evaporation of the constituent ele-

ments in an overpressure of Se, or by any combination of methods that will produce a phase-separated mixture of these compounds.

**[0022]** In other variations, the initial deposition does not have to include both of the compounds $Cu(In,Ga)Se_2$ and $Cu_xSe$ for the large-grain precursor mixture. It can start instead with an initial deposition of a binary $Cu_{2-\delta}$ Se precursor as an extreme case of the $Cu(In,Ga)Se_2$:$Cu_{2-\delta}Se$ large-grain precursor mixture, in which case the In and/or Ga would have to be added in a manner and at a temperature in which phase-separated $Cu(In,Ga)Se_2$:$Cu_xSe$ would be produced on the substrate, such as by the addition of a small amount of $In_2Se_3$. Of course, the initial deposition of $Cu_{2-\delta}Se$ should be at a lower temperature to get the desired large-grain formation. The formation of the precursor can be dissected further by the conversion of an elemental mixture of Cu,(In,Ga), and Se to the compound mixture by exposure to Se vapor at elevated temperatures, or by the conversion of Cu and (In,Ga) to $Cu(In,Ga)Se_2$ by exposure to $H_2Se$. At the other extreme, an initial deposition of $In_2Se_3$ could be made in conjunction with a larger amount of $Cu_2Se$. The goal, regardless of which combination or sequence of materials deposition is used, is to achieve the Cu-rich, phase separated growth of the $Cu(In,Ga)Se_2$:$Cu_xSe$ mixture in the first step of the process, so that the second step can proceed according to that portion of this invention. Also, additional Cu as well as, or instead of, the additional In can be incorporated in the second step.

## Examples

**[0023]** Absorbers according to this invention were fabricated by a combination of physical vapor deposition and $H_2Se$/Se vapor selenization on 5-cm x 5-cm (2-in x 2-in) Mo-coated soda-lime silica (SLS) and bare 7059 glass at substrate temperatures in excess of 550°C. At times, an intentional one-dimensional compositional gradient was introduced across the 5-cm substrate to facilitate the study of novel device structures and the relationship between device parameters and film composition. Absorbers included $CuInSe_2$, $CuIn_{1-x}Ga_xSe_2$ ($0.0 \leq x \leq 0.25$), and $CuGaSe_2/CuInSe_2$ layered structures. Surface and bulk material characterization were accomplished by Auger electron spectroscopy (AES), X-ray and ultraviolet photoemission spectroscopy (XPS, UPS), X-ray and transmission-electron diffraction (XRD, TED), photoluminescence (PL), and analytical scanning electron microscopy (ASEM). Device characterization was accomplished by dark and light I-V and spectral response at temperatures down to 50K, capacitance-voltage, and deep-level transient spectroscopy (DLTS).

**[0024]** We were successful in producing device quality $CuInSe_2$ based thin films on bare glass and Mo-coated SLS with columnar structures and a lateral grain size of 2.0-10.0 μm. XRD studies suggest monocrystalline behavior on bare substrates, and (112) high preferred orientation on Mo-coated substrates. XRD and TED confirmed the presence of a CuPt-type ordering of Cu and In planes within the bulk of the film. We attribute the creation of this phase to the high substrate temperatures and liquid-phase assisted growth processes present.

**[0025]** In film structures with an overall Cu-rich composition, the $Cu_2Se$ binary phase was identified at the surface by XPS and within the bulk by EDS of thinned samples prepared in cross section for TED. In film structures with an overall Cu-poor composition, the $CuIn_2Se_{3.5}$ ϒ" ordered-vacancy compound (OVC) phase was observed in the bulk by XRD and TED, while the $CuIn_3Se_5$ ϒ" OVC is exclusively observed at the surface. Electrical characterization of the ϒ" and ϒ" phases [3] indicated enhanced transport properties and n-type behavior. Electrical activity within the grain and at grain-boundaries in these films were not discernibly different.

**[0026]** Process-dependent device structures included both sharp heterojunctions and deep homojunctions, with an observed space-charge width of up to 2.5μm. Heterojunction cells were completed with either a thick CdS window layer deposited by physical vapor deposition, or with a chemical-bath deposition (CBD) CdS (700Å)/ZnO (0.5 μm) layered window. Photovoltaic (PV) devices with conversion efficiencies in excess of 12% and most recently over 13.7% have been demonstrated. Films that were fabricates with an intentional compositional gradient exhibited an open-circuit voltage ($V_{oc}$) vs. composition dependence, while the short-circuit current ($J_{sc}$) remained constant over a wide compositional range. A very promising structure involved the growth of $CuInGaSe_2$ on $CuGaSe_2$. Open circuit voltages ranging from 550 to 630 mv and $J_{sc}$'s ranging from 37 to 30 $mA/cm^2$ have been observed, respectively. Thus result suggests total area device efficiencies greater than 15% are possible. The voltage parameter was significant in light of the analysis (AES depth profiling and spectral response), which measured a surface and content less than that usually required to obtain the device parameters quoted. It is suggested that a back-surface field from the $CuGaSe_2$ was contributing to the voltage enhancement of the $CuInSe_2$ absorber. We anticipate significant improvements in the near future as the processes are optimized.

**[0027]** We have been successful in producing enhanced-grain device-quality $Cu(In,Ga)Se_2$ by a simple two-stage process. The first stage of the process involved the growth of an enhanced-grain $CuInSe_2$ aggregate mixture. At high substrate temperatures, the growth of the $CuInSe_2$ occurred in a liquid rich environment, which accounted for the increase in average grain size of the film mixture. When the vapor flux became In-rich, the $CuInSe_2$ formed at the surface remained in solution while it diffused to the liquid-solid interface, where it condensed, nucleated and "epitaxial" built on the original $CuInSe_2$ surface. When the liquid phase was consumed, the process was terminated in some

samples and in others by In diffusion into the bulk or by the growth of very Cu-poor phases near the surface. The latter step determined the homo-or hetero junction nature of the device. This generalized procedure may be applied to scalable manufacturing processes, like sputtering and selenization, in a very reproducible manner.

**[0028]** The foregoing description is considered as illustrative only of the principles of the invention. Further, since numerous modifications and changes will readily occur to those skilled in the art, it is not desired to limit the invention to the exact construction and process shown as described above. Accordingly, all suitable modifications and equivalents may be resorted to falling within the scope of the invention as defined by the claims which follow.

## Claims

1. A process for fabricating thin film semiconductor devices, comprising the steps of:

   forming a Cu-rich, phase separated, compound mixture (20) comprising $Cu(In,Ga)Se_2$:$Cu_xSe$ (16;18) on a substrate (12); and
   converting $Cu_xSe$ (18) in the mixture (20) to $Cu_w(In,Ga)_ySe_z$ by exposing said $Cu_xSe$ (18) to (In,Ga) and Se.

2. The process of claim 1, including the step of forming said mixture (20) in a temperature range of about 500-600°C.

3. The process of claim 1, including the step of converting said $Cu_xSe$ (18) to $Cu_w(In,Ga)_ySe_z$ in a temperature range of about 500-600°C.

4. The process of claim 3, including the step of converting said $Cu_xSe$ (18) to $Cu(In,Ga)Se_2$.

5. The process of claim 1, including the step of converting said $Cu_xSe$ (18) to $Cu_w(In,Ga)_ySe_z$ in a temperature range of about 300-400°C.

6. The process of claim 5, including the step of converting said $Cu_xSe$ (18) to $Cu_2(In,Ga)_4Se_7$.

7. The process of claim 5, including the step of converting said $Cu_xSe$ (18) to $Cu(In,Ga)_3Se_5$.

8. The process of claim 1, wherein $1 \leq x \leq 2$.

9. The process of claim 1, wherein the ratio of $Cu(In,Ga)_2$:$Cu_xSe$ (16;18) is about 1:2.

10. The process of claim 1, wherein Cu comprises about 40-50 atomic percent of said mixture (20).

11. The process of claim 1, including the step of exposing said $Cu_xSe$ (18) to $In_ySe_z$.

12. The process of claim 11, including the step of exposing said $Cu_xSe$ (18) to $In_2Se_3$.

13. The process of claim 1, including the step of exposing said $Cu_xSe$ (18) to In vapor (22) and Se vapor (24).

14. The process of claim 1, including the step of forming said mixture (20) by depositing said $Cu(In,Ga)Se_2$ and said $Cu_xSe$ on said substrate.

15. The process of claim 14, including the step of forming said mixture (20) by depositing $Cu(In,Ga)Se_2$ and $Cu_xSe$ on said substrate simultaneously.

16. The process of claim 14, including the step of forming said mixture (20) by depositing $Cu(In,Ga)Se_2$ and $Cu_xSe$ sequentially.

17. The process of claim 1, including the step of forming said mixture (20) by depositing $Cu_xSe$ and $In_ySe_z$.

18. The process of claim 17, including the step of depositing said $Cu_xSe$ and said $In_ySe_z$ sequentially.

19. The process of claim 17, including the step of depositing said $Cu_xSe$ and said $In_ySe_z$ simultaneously.

20. The process of claim 7, where said $Cu_xSe$ is further defined by $1 \leq x \leq 2$, and where said $In_ySe_z$ is further defined by y=2 and z=3.

21. The process of claim 17, including the step of depositing said $Cu_xSe$ by first depositing Cu and then exposing said Cu to Se.

22. The process of claim 14, including the step of depositing said $Cu(In,Ga)Se_2$ by depositing an elemental mixture of Cu and (In,Ga) and exposing said mixture to Se.

23. The process of claim 14, including the step of depositing said mixture (20) by sputtering.

24. The process of claim 14, including the step of depositing said mixture (20) by physical co-evaporation.

25. The process of claim 1, wherein said substrate (12) comprises glass.

26. The process of claim 25, wherein said substrate (12) comprises a Mo coating (14) on said glass.

**Patentansprüche**

1. Verfahren zur Herstellung von Dünnfilmhalbleitervorrichtungen, das folgende Schritte aufweist:

   Ausbildung einer Cu-reichen, phasengetrennten Verbundmischung (20), die Cu(In,Ga)$Se_2$:$Cu_xSe$ (16; 18) auf einem Substrat (12); und
   Umwandlung des $Cu_xSe$ (18) in der Mischung (20) zu $Cu_w(In,Ga)_ySe_z$ durch Aussetzen des $Cu_xSe$ (18) gegen (In,Ga) und Se.

2. Verfahren nach Anspruch 1, das den Schritt der Ausbildung der Mischung (20) in einem Temperaturbereich von ungefähr 500-600°C aufweist.

3. Verfahren nach Anspruch 1, das den Schritt der Umwandlung des $Cu_xSe$ (18) zu $Cu_w(In,Ga)_ySe_z$ in einem Temperaturbereich von ungefähr 500-600°C aufweist.

4. Verfahren nach Anspruch 3, das den Schritt der Umwandlung des $Cu_xSe$ (18) in Cu(In,Ga)$Se_2$ aufweist.

5. Verfahren nach Anspruch 1, das den Schritt der Umwandlung des $Cu_xSe$ (18) in $Cu_w(In,Ga)_ySe_z$ in einem Temperaturbereich von ungefähr 300-400°C aufweist.

6. Verfahren nach Anspruch 5, das den Schritt der Umwandlung des $Cu_xSe$ (18) in $Cu_2(In,Ga)_4Se_7$ aufweist.

7. Verfahren nach Anspruch 5, das den Schritt der Umwandlung des $Cu_xSe$ (18) in $Cu(In,Ga)_3Se_5$ aufweist.

8. Verfahren nach Anspruch 1, wobei $1 \leq x \leq 2$ ist.

9. Verfahren nach Anspruch 1, wobei das Verhältnis von $Cu(In,Ga)_2$:$Cu_xSe$ (16; 18) ungefähr 1:2 ist.

10. Verfahren nach Anspruch 1, wobei Cu ungefähr 40-50 Atomprozent der Mischung (20) stellt bzw. aufweist.

11. Verfahren nach Anspruch 1, das den Schritt des Aussetzens des $Cu_xSe$ (18) gegen $In_ySe_z$ aufweist.

12. Verfahren nach Anspruch 11, das den Schritt des Aussetzens des $Cu_xSe$ (18) gegen $In_2Se_3$ aufweist.

13. Verfahren nach Anspruch 1, das den Schrift des Aussetzens des $Cu_xSe$ (18) gegen In-Dampf (22) und gegen Se-Dampf (24) aufweist.

14. Verfahren nach Anspruch 1, das den Schrift der Ausbildung der Mischung (20) durch Abscheiden des Cu(In,Ga)$Se_2$ und des $Cu_xSe$ auf dem Substrat aufweist.

15. Verfahren nach Anspruch 14, das den Schritt der Ausbildung der Mischung (20) durch Abscheiden von Cu(In,Ga)$Se_2$ und $Cu_xSe$ auf dem Substrat simultan aufweist.

16. Verfahren nach Anspruch 14, das den Schrift der Ausbildung der Mischung (20) durch Abscheiden von Cu(In,Ga)$Se_2$ und $Cu_xSe$ aufeinanderfolgend aufweist.

17. Verfahren nach Anspruch 1, das den Schrift der Ausbildung der Mischung (20) durch Abscheiden von $Cu_xSe$ und $In_ySe_z$ aufweist.

18. Verfahren nach Anspruch 17, das den Schrift des Abscheiden des $Cu_xSe$ und des $In_ySe_z$ aufeinanderfolgend aufweist.

19. Verfahren nach Anspruch 17, das den Schrill des Abscheidens des $Cu_xSe$ und des $In_ySe_z$ simultan aufweist.

20. Verfahren nach Anspruch 7, wobei das $Cu_xSe$ ferner definiert ist durch $1 \leq x \leq 2$, und wobei das $In_ySe_z$ ferner definiert ist durch y=2 und z=3.

21. Verfahren nach Anspruch 17, das den Schritt des Abscheidens des $Cu_xSe$ durch eine erste Abscheidung von Cu und dann das Aussetzen des Cu gegen Se aufweist.

22. Verfahren nach Anspruch 14, das den Schritt des Abscheidens von Cu(In,Ga)$Se_2$ durch Abscheidung einer Elementmischung von Cu und (In,Ga) und das Aussetzen der Mischung gegen Se aufweist.

23. Verfahren nach Anspruch 14, das den Schritt des Abscheidens der Mischung (20) durch Sputtern aufweist.

24. Verfahren nach Anspruch 14, das den Schritt des Abscheidens der Mischung (20) durch physikalische Koverdampfung aufweist.

25. Verfahren nach Anspruch 1, wobei das Substrat (12) Glas aufweist.

26. Verfahren nach Anspruch 25, wobei das Substrat (12) eine Mo-Beschichtung (14) auf dem Glas aufweist.

## Revendications

1. Procédé de fabrication de dispositifs semiconducteurs en couches minces comprenant les étapes suivantes :

   former un mélange complexe, séparé en phase, riche en Cu (20) comprenant $Cu(In,Ga)Se_2$:$Cu_xSe$ (16 ; 18) sur un substrat (12) ; et
   convertir $Cu_xSe$ (18) dans le mélange (20) an $Cu_w(In,Ga)_ySe_z$ en exposant le $Cu_xSe$ (18) à (In,Ga) et à Se.

2. Procédé selon la revendication 1, comprenant l'étape consistant à former le mélange (20) dans une plage de température d'environ 500 à 600°C.

3. Procédé selon la revendication 1, comprenant l'étape consistant à convertir $Cu_xSe$ (18) an $Cu_w(In,Ga)_ySe_z$ dans une plage de température d'environ 500 à 600°C.

4. Procédé selon la revendication 3, comprenant l'étape consistant à convertir $Cu_xSe$ (18) en $Cu(In,Ga)Se_2$.

5. Procédé selon la revendication 1, comprenant l'étape consistant à convertir $Cu_xSe$ (18) an $Cu_w(In,Ga)_ySe_z$ dans une plage de température d'environ 300 à 400°C.

6. Procédé selon la revendication 5, comprenant l'étape consistant à convertir $Cu_xSe$ (18) an $Cu_2(In,Ga)_4Se_7$.

7. Procédé selon la revendication 5, comprenant l'étape consistant à convertir $Cu_xSe$ (18) an $Cu(In,Ga)_3Se_5$.

8. Procédé selon la revendication 1, dans lequel $1 \leq x \leq 2$.

9. Procédé selon la revendication 1, dans lequel le rapport de $Cu(In,Ga)Se_2$:$Cu_xSe$ (16 ; 18) est d'environ 1/2.

10. Procédé selon la revendication 1, dans lequel Cu constitue environ 40 à 50 % en atomes du mélange (20).

11. Procédé selon la revendication 1, comprenant l'étape composant à exposer le $Cu_xSe$ (18) à $In_ySe_z$.

12. Procédé selon la revendication 11, comprenant l'étape composant à exposer $Cu_xSe$ (18) à $In_2Se_3$.

13. Procédé selon la revendication 1, comprenant l'étape consistant à exposer $Cu_xSe$ (18) à une vapeur d'In (22) et à une vapeur de Se (24).

14. Procédé selon la revendication 1, comprenant l'étape consistant à former le mélange (20) en déposant $Cu(In,Ga)Se_2$ et $Cu_xSe$ sur ledit substrat.

15. Procédé selon la revendication 14, comprenant l'étape consistant à former le mélange (20) en déposant $Cu(In,Ga)Se_2$ et $Cu_xSe$ simultanément sur le substrat.

16. Procédé selon la revendication 14, comprenant l'étape consistant à former le mélange (20) en déposant $Cu(In,Ga)Se_2$ et $Cu_xSe$ séquentiellement.

17. Procédé selon la revendication 1, comprenant l'étape consistant à former le mélange (20) en déposant $Cu_xSe$ et $In_ySe_z$.

18. Procédé selon la revendication 17, comprenant l'étape consistant à déposer $Cu_xSe$ et $In_ySe_z$ séquentiellement.

19. Procédé selon la revendication 17, comprenant l'étape consistant à déposer $Cu_xSe$ et $In_ySe_z$ simultanément.

20. Procédé selon la revendication 7, dans lequel $Cu_xSe$ est en outre défini par $1 \leq x \leq 2$, et $In_ySe_z$ est en outre défini par y=2 et z=3.

21. Procédé selon la revendication 17, comprenant l'étape consistant à déposer le $Cu_xSe$ en déposant d'abord Cu et en exposant ensuite Cu à Se.

22. Procédé selon la revendication 14, comprenant l'étape consistant à déposer le $Cu(In,Ga)Se_2$ en déposant un mélange élémentaire de Cu et (In,Ga) et en exposant le mélange à Se.

23. Procédé selon la revendication 14, comprenant l'étape consistant à déposer le mélange (20) par pulvérisation.

24. Procédé selon la revendication 14, comprenant l'étape consistant à déposer le mélange (20) par co-évaporation physique.

25. Procédé selon la revendication 1, dans lequel le substrat (12) comprend du verre.

26. Procédé selon la revendication 25, dans lequel le substrat (12) comprend un revêtement de Mo (14) sur le verre.

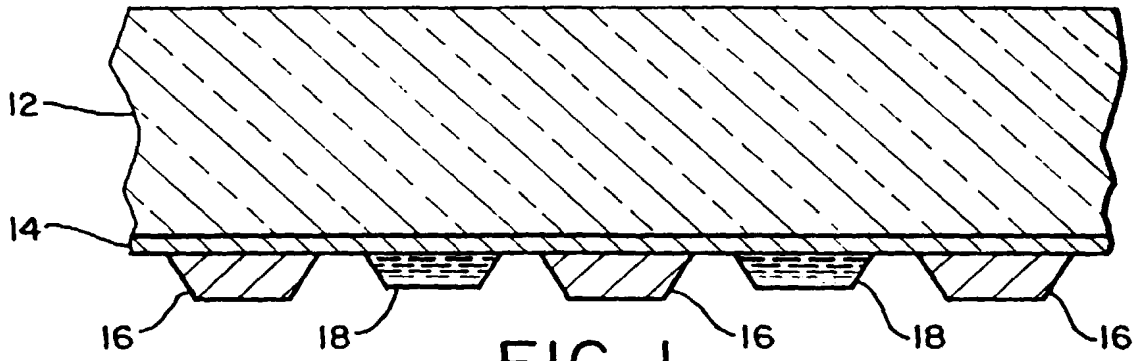


FIG. 1

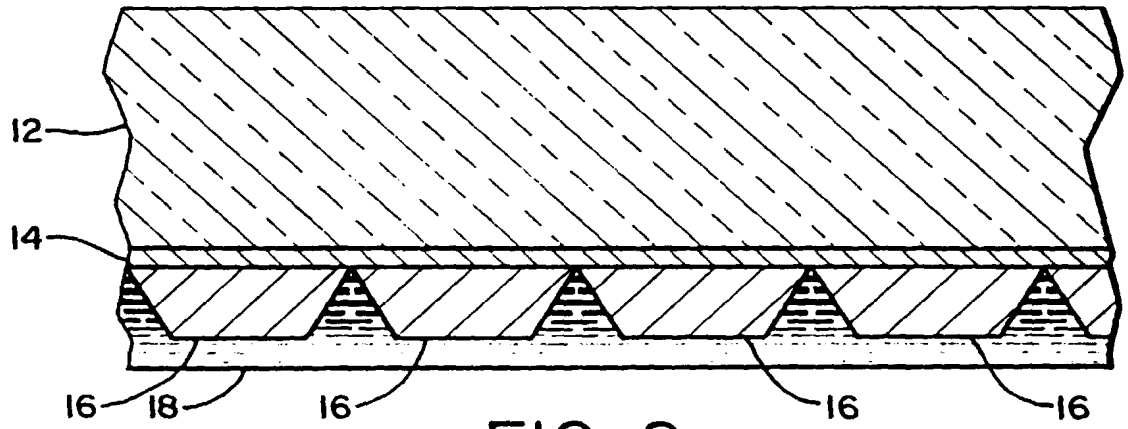


FIG. 2

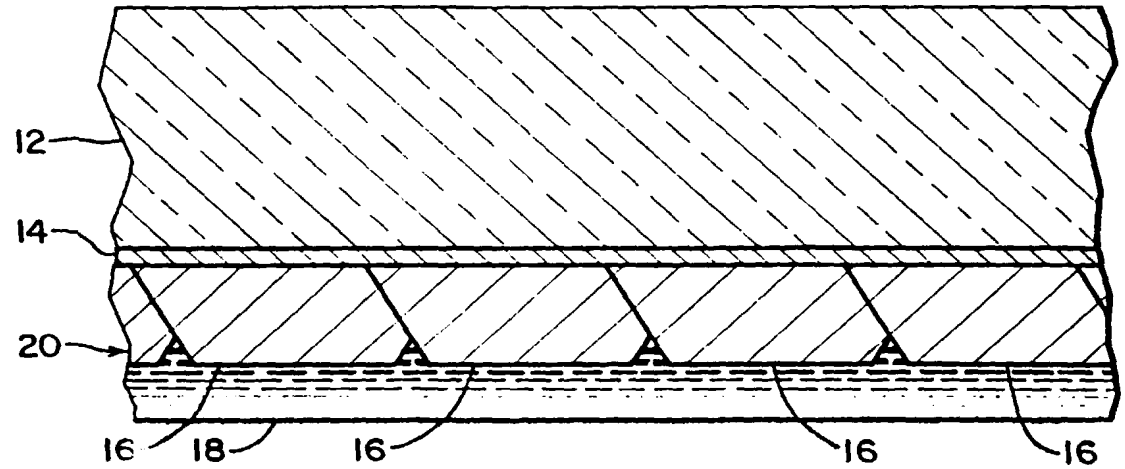


FIG. 3

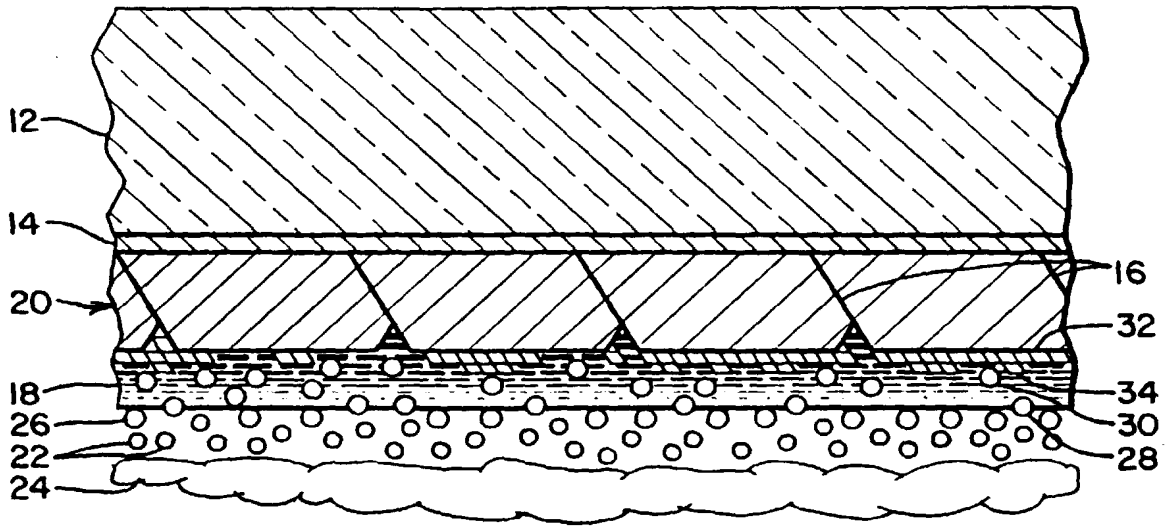


FIG. 4

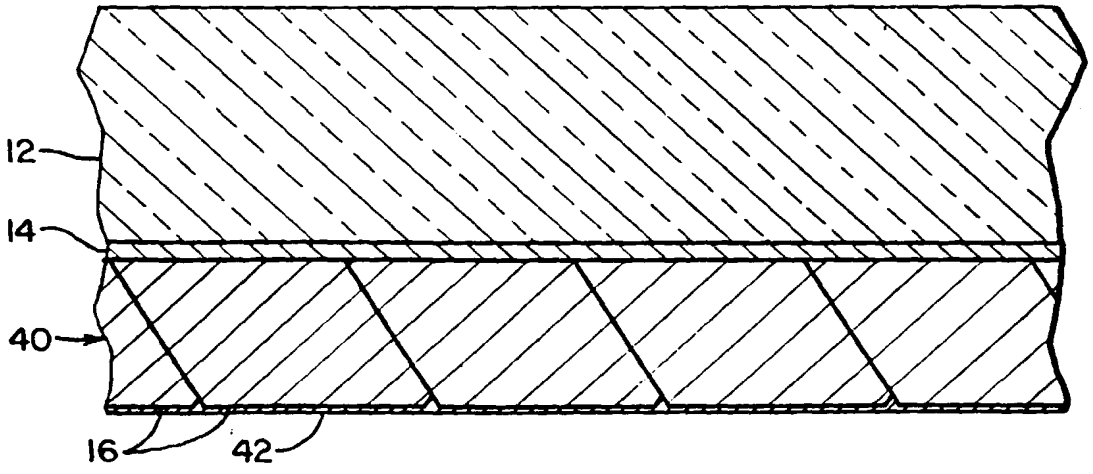


FIG. 5

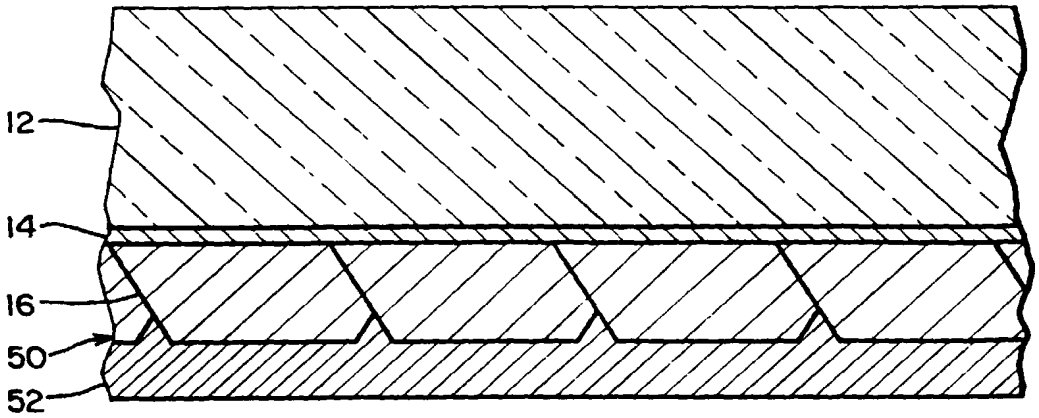
12
14
16
50
52

FIG 6

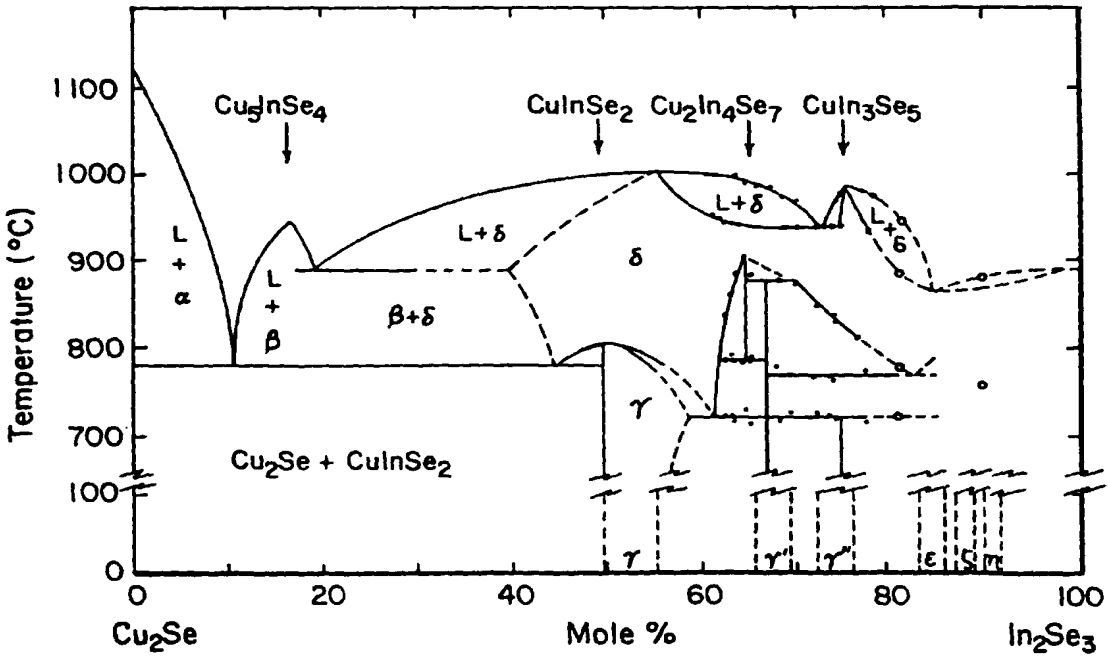
Cu5InSe4
CuInSe2
Cu2In4Se7
CuIn3Se5
L+δ
L+δ
L+δ
δ
L + α
L + β
β+δ
γ
Cu2Se + CuInSe2
Temperature (°C)
1100
1000
900
800
700
100
0
0
20
40
60
80
100
Cu2Se
Mole %
In2Se3

FIG. 7